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Title: BEAM DIAGNOSTIC SUITE FOR THE SNS LINAC

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Beam Diagnostic Suite for the SNS Linac*

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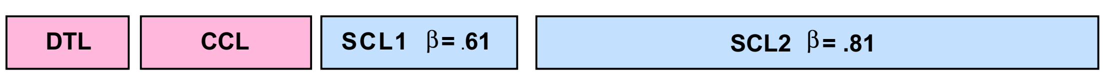
Abstract. The Spallation Neutron Source (SNS) is the next-generation pulsed neutron source to be built in the United States. The accelerator chosen to produce the 2-MW beam power on the neutron-producing target is an H^- linear accelerator (linac) to 1 GeV, followed by a proton accumulator ring. The ring compresses the 1-ms-long beam bunches from the linac to less than 1 s. The linac is pulsed at 60 Hz with a 6% duty factor. Stringent control of the pulse structure and stability of the high-intensity H^- beam is needed to minimize beam loss in the linac and to optimize injection into the accumulator ring. This requires a set of beam diagnostics that can operate at high peak currents (~52 mA) with high sensitivity and minimum beam interception.

INTRODUCTION

To provide a reference for discussion of the diagnostics, Fig. 1 shows the overall layout of the current design for the Spallation Neutron Source (SNS) linac, including a drift-tube linac (DTL), coupled-cavity linac (CCL), and two sections of superconducting linac (SCL). The linac is being designed and built by Los Alamos and Jefferson National Laboratories as part of a six-Lab collaboration. Discussion of required beam parameters and early linac designs can be found in references [1-3]; the current baseline is documented in the March 2000 DOE review [4].



	DTL	CCL	SCL1	SCL2	Total
W_{final} (MeV)	86	185	375	1000	
Klystrons	6 (2.5 MW)	4 (5 MW)	33 (0.5 MW)	68 (0.5 MW)	111
Cryostats	-	-	11	17	28
Length (m)	36.5	56.5	64.2	136.7	294

FIGURE 1. The layout and key features of the SNS linac design as of May 2000.

At its full design power of 2 MW, the SNS linac accelerates a chopped, 52-mA-peak H^- beam with subsequent charge-changing injection into an accumulator ring. The high intensity and negative ion acceleration present special challenges on beam quality and handling but also allow unique opportunities for diagnostics.

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List of Linac Beam Diagnostics

Beam diagnostics form an integral part of accelerator design and operation. For a high current accelerator such as the SNS, the type and placement of beam diagnostics is crucial to provide rapid, accurate information on beam characteristics with minimum interception of the beam. Following several SNS collaboration meetings to discuss beam control and commissioning requirements for the linac, Los Alamos generated the following list for the linac beam diagnostics.

TABLE 1. List of SNS Linac Diagnostics.

Type	Abbreviation	Number
Beam Position & Phase	BPM	62
Beam Loss Monitor	BLM	94
Phase Width	-	1
Beam Current Monitor	BCM	13
Wire Scanner	WS	44
Harp	-	7
Video Profile	-	1
Beam-in-Gap	BIG	1
Emittance	-	1

From the table, one can see that some of these diagnostics are required in fairly large numbers. This places a premium on low-cost instruments that are easy to fabricate and maintain. The budget for linac diagnostics is about $10 M, including design, fabrication, installation, and checkout. This is less than 5% of the overall linac cost, estimated to be ~$230 M.

In the following sections, we describe the function and current plans for some of these diagnostic systems.

BEAM POSITON AND PHASE

Throughout most of the linac, the beam has an rms radius of about 1 mm with a maximum extent about seven times rms, or less than ~1 cm. Since apertures in the linac RF structures are only ~1.25-cm radius in the DTL and ~2-cm radius in the CCL, accurate positioning of the beam is a requirement. Information about the transverse position of the beam delivered by the BPMs is used to steer the beam in the linac with steering magnets. In addition, using the summed signals from the BPMs provides an excellent way to measure the beam phase, required for tuning the RF cavities.

BPM & Phase Electronics

The BPM and Phase System is designed to measure beam centroid positions to –0.13 mm and phase to –1.5 degrees. Signals from each BPM pickup will be processed to measure both beam position and beam phase, reducing the total number of required pickups. The position measurement electronics are based on a logarithmic detector circuit that shows good linearity over a wide dynamic range [5]. Versions will be designed for direct measurement of the fundamental and first harmonic of the

402.5-MHz beam frequency, depending on the measurement location. Signals from the four BPM lobes are also summed and then down-converted to a 50-MHz intermediate frequency (IF). The phase measurement technique involves sampling the IF signals with an ADC that is clocked at 40 MHz to create in-phase and quadrature-phase (IQ) vectors [6]. These vectors then define the phase relationship of the beam at the location of each pickup

BPM & Phase Pickup

The BPM pickups are based on four-lobe, 50-Ω striplines that detect the 402.5-MHz signal (or a low harmonic) from the RF structure of the beam. To simplify the design and minimize vacuum penetrations, we plan to terminate the striplines at the downstream end. A test model has been constructed of such a pickup for testing the electronic properties. Below are views of the test device, which has a bore diameter of 4 cm and a pickup length of 4 cm.

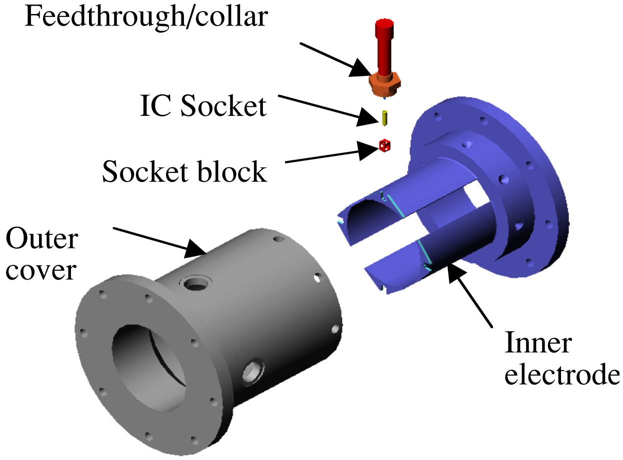

FIGURE 2. BPM Prototype exploded view

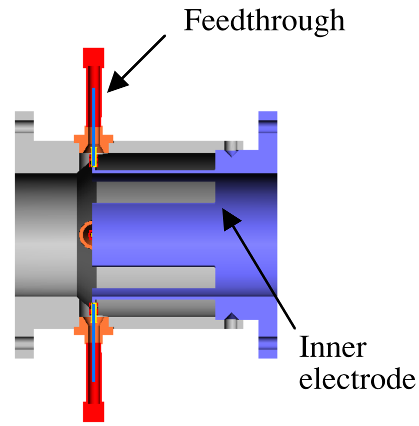

FIGURE 3. BPM prototype side view

Because of space limitations, the final design of these BPMs must be closely integrated with the mechanical design of the linac. In the DTL, we plan to insert special pickups in two empty drift tubes (those without focusing magnets) in each of the six tanks. Because of interference from the 402.5-MHz power, these pickups can only be used when the respective DTL tank is unpowered. For the CCL and SCL, the pickups will be integrated into the inter-segment regions and aligned along with the focusing quadrupoles using a taut-wire technique.

BPM Electromagnetic Calculations

Electromagnetic calculations of the pickups, including inter-lobe coupling, have been performed and will be reported in a paper at this conference [7]. We used the electromagnetic (EM) code package MAFIA to perform 2-D and 3-D calculations to adjust the BPM cross-section parameters to 50-Ω and to calculate the electrode coupling. Since the signal power in a BPM transducer for a given beam current can be increased by increasing the length and width of the electrodes (lobes), we investigated both the linearity and coupling between lobes for several configurations. Fig. 4 shows the linearity results for the configuration used. Details of the calculations can be found in Ref [7].

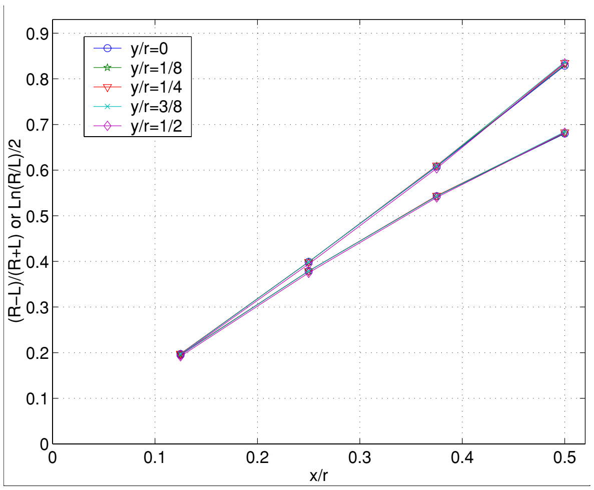

FIGURE 4. MAFIA results for horizontal ratio S of the signal harmonics at 402.5 MHz (top lines for S=ln($_R$/ $_L$)/2, bottom ones for S=($_R$- $_L$)/($_R$+ $_L$)) versus the beam horizontal displacement x/r_b, for a few values of the beam vertical displacement y/r_b (see legend).

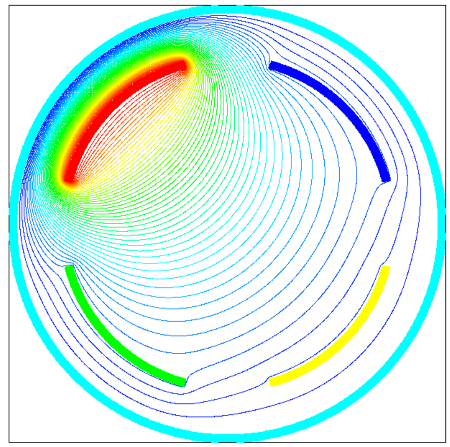

FIGURE 5: Electrostatic coupling in the BPM with 60° electrodes. The electrode at upper left has a voltage applied and the circular lines are equipotential contours.

The coupling between BPM electrodes was calculated in a static approximation and using the dynamical 3-D solution. In both cases, the coupling coefficients are defined as ratios of the potentials or voltage amplitudes for two adjacent electrodes, and for two opposite ones. Fig.˚5 illustrates the static coupling between the BPM electrodes that subtend 60°. Studies were also done using 45° electrodes and with separators between lobes. The detailed results of these calculations [7] show that the separators reduce coupling but 60° electrodes without separators are adequate and also have better linearity.

BEAM PROFILE

The standard method of measuring beam profiles is with wire scanners. In collaboration with the other Labs involved in SNS, we have decided to standardize on a slow-wire scanner using a linear stepping motor and secondary electron emission from a carbon or silicon-carbide wire for most of the linac. Because of the high peak intensity of the beam, very thin (~50- m-diameter) wires will be used and then only at low repetition rate and pulse length.

Tungsten Wire Scanner

For the superconducting part of the linac, a carbon-based wire is not suitable because of vacuum requirements. Shafer [8] has examined using a tungsten wire in this application. The disadvantage over carbon is tungsten s high density and low specific heat, which together contribute to a very high temperature rise in pulsed beams.

Plots of the peak wire temperature vs. time for 1-Hz operation with 50- s-long pulses of peak SNS intensity (52 mA) are shown below for a 100- m-diameter tungsten wire. The peak temperature reaches about 2142 C at 185 MeV and 1343 C at 1000 MeV for these conditions. These are well below the melting point of tungsten at 3370 C. However, the thermionic emission at 1600 C is about 1 A and rises quickly to about 60 A at 1900 C for typical wire lengths. This is comparable to the current expected from secondary emission of 10 to 20 A. Shafer therefore concludes that tungsten wires can be used in this application, but monitoring of the beam loss from an external BLM as the wire is moved through the beam may give a more accurate representation of the beam intensity.

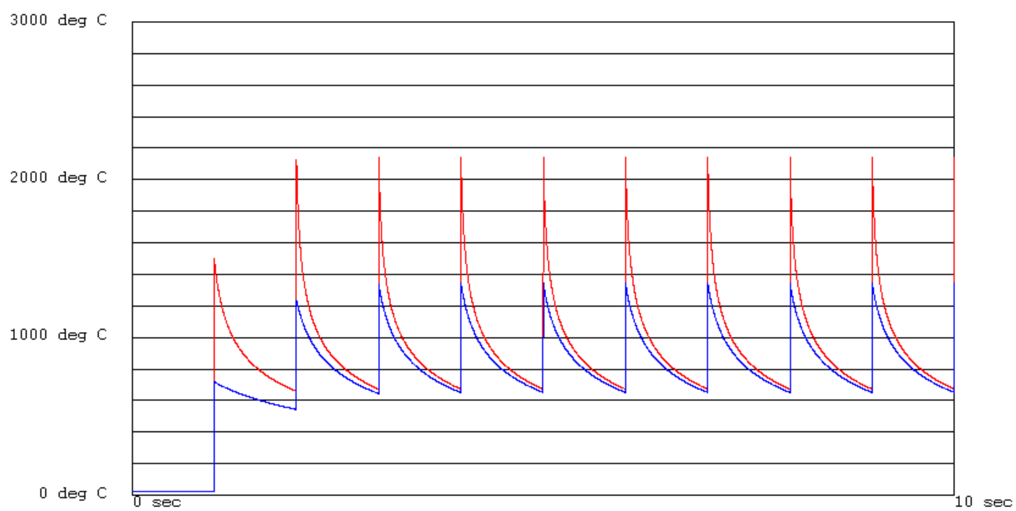

FIGURE 6. Wire temperature vs. time for a 100- m-diameter tungsten wire for 185 MeV (upper) and 1000 MeV (lower) H^- beam as specified in the text.

Harps

For low-power tune-up in the linac, the use of multi-wire harps is being considered. We have successfully used such devices in high-peak-current applications to obtain rapid profiles in a single pulse [9]. For the beam size in the linac of ~1-cm full radius, the harp wires must be spaced at less than ~1 mm to obtain sufficient resolution. Using very thin (~50- m-thick) carbon or silicon-carbide wires for these devices looks feasible from both signal-to-noise and lifetime perspectives. To reduce activation from the use of these devices, however, one must operate not only at low repetition rates (~1 Hz) but at short pulse lengths (~50 to 100 s). The present plan is to have an insertable harp on a tune-up diagnostic plate and installed in three locations along the

DTL. Los Alamos is also building large-diameter harps as permanent beam-size monitors in front of each of the SNS beam dumps and the spallation target.

Other Profile Devices

Other considerations, such as activation of nearby components and additional heat load on the cryomodules can be problematic for slow-wire scanners. For these reasons, both a flying wire (traveling through the beam at a speed of ~ 5 m/s) and a laser wire (to strip a narrow portion of the H^- beam) are alternatives that are being investigated [10].

Los Alamos is also considering using fluorescence of the beam in residual gas for a non-interceptive profile monitor at low energies. This technique has been used in the GTA accelerator and is currently being used in the APT project [11].

BEAM CURRENT

Beam current toroids will be used throughout the linac to monitor both average and peak currents. For average currents, we plan a DC current transformer or a single-core toroid with integration. The specifications are to measure up to 2-mA average beam current with a absolute accuracy of about 1% and a precision of about 0.5%. These will be located between the six DTL tanks and at several inter-module locations in the CCL and SCL. Differential currents will be continuously monitored and used as input into the fast beam-abort signal.

For measuring details of the bunch structure in the beam, the summed signals from BPMs will be used. Although these BPM signals give a precise representation of relative beam current, they will not be used for total beam or differential measurements.

BEAM-IN-GAP

One of the most significant possible sources of beam loss in the SNS is beam remaining in the ~1-MHz chopping gap that is used for extraction from the ring. The requirement is that any beam in this ~300-ns-long gap must be at a level of 10^{-5} or lower of the peak intensity. This is a challenging measurement, but one which we believe is possible and, because of its importance to ring activation, necessary.

Shafer [12] has published the beam-in-gap (BIG) technique we plan for this measurement, only a brief summary of which is included here. The threshold for photo-detachment of H^- ions is 0.75 eV, and the maximum detachment cross section is 4×10^{-17} cm^2 at 1.5 eV. A commercially available 50-mJ/pulse Q-switched Nd:YAG laser can neutralize a significant fraction of the H^- beam in a single 10-ns-long laser pulse. A dipole magnet will separate the neutral beam from the H^- beam to allow diagnostics on the neutral beam without intercepting the high-current H^- beam

For the SNS, the H^- beam from the linac traverses a 90-degree bend prior to injection into the accumulator ring, and this provides suitable opportunities to insert a

BIG system. The following figure shows the layout of the system that is currently planned.

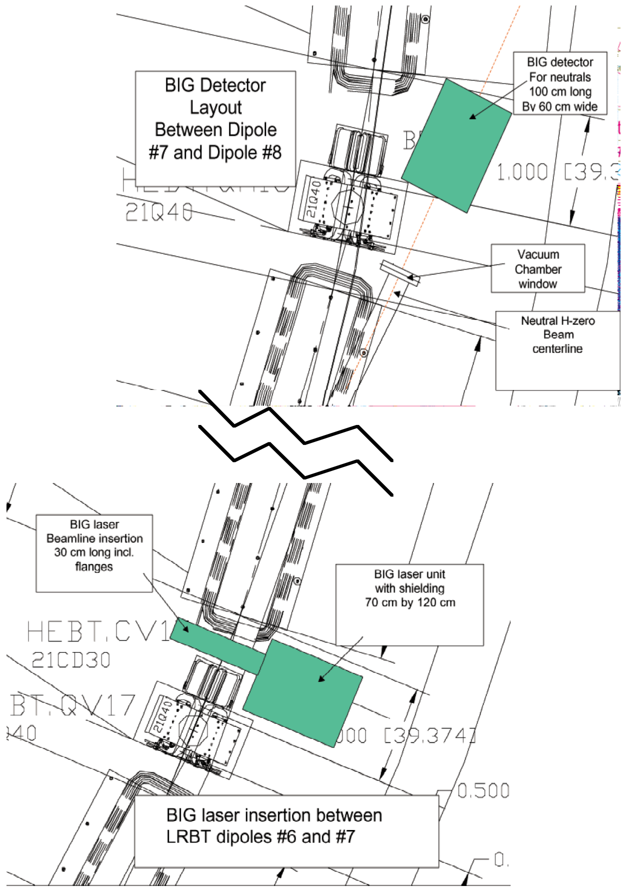

FIGURE 7. Layout of the BIG apparatus in the SNS 90-degree bend following the linac.

We have evaluated the suitability of several types of detectors for collecting the neutralized beam [13]. The requirement is for adequate sensitivity, good time response, and ability to reject or shield background from neutron and gamma radiation. For a single-pass Nd:YAG, 1.06-micron laser with a 200 mJ, 12-ns-long pulse Ref. [13] calculates a stripped H^0 yield of 16% for a 1-GeV beam. One would then have to detect 6 x 10^4 particles to observe gap intensity at a level of 10^{-4} of the peak beam current of 52 mA. Although several detectors such as a secondary-emission monitor (SEM), a Cerenkov radiator, or an organic scintillator have the necessary sensitivity, the Cerenkov detector is preferred because of its faster risetime, allowing better temporal resolution, and its relative insensitivity to background radiation. Further investigation and development are in progress.

OTHER DIAGNOSTICS

From the Table 1, one can see that several other diagnostic devices are planned for the SNS linac. The BLM system for detecting ionizing radiation in the linac tunnel is crucial, not only for machine protection, but as a sensitive tuning diagnostic. For determining the phase width of the beam, we plan a special pickup with Fourier-transform processing at the end of the linac. Online emittance measurements are not feasible in the linac, but we are building a diagnostic plate (D-plate) that will be used in commissioning to fully characterize the beam. The D-plate will include standard diagnostic devices plus a slit-and-collector system to measure beam emittance.

SUMMARY

We have defined an initial suite of diagnostic instrumentation for characterizing the SNS linac beam. As the design and commissioning plan are further developed, these will be the starting points for detailed designs.

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